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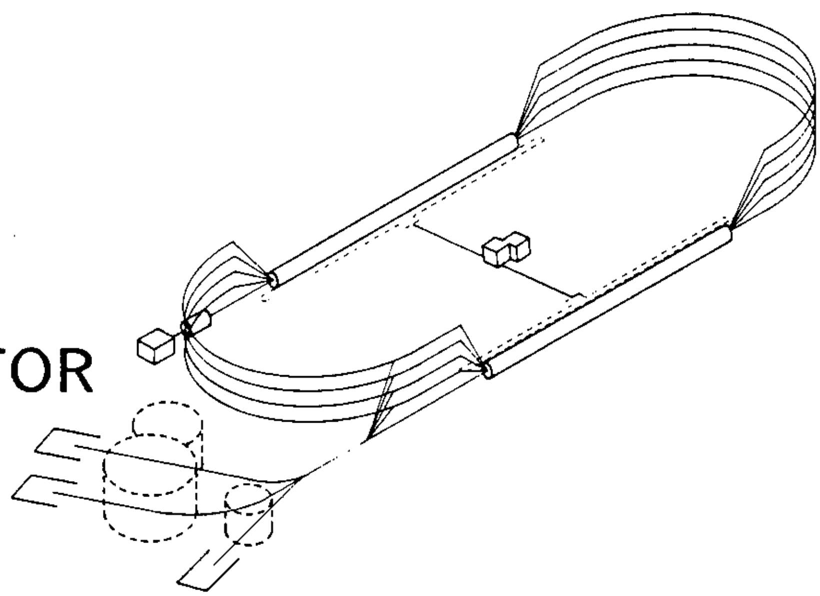

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USE OF THE TACL SYSTEM AT CEBAF FOR CONTROL OF THE CRYOGENIC TEST FACILITY

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Abstract

A logic-based control software system, called Thaumaturgic Automated Control Logic (TACL), is under development at the Continuous Electron Beam Accelerator Facility in Newport News, VA. The first version of the software was placed in service in November, 1987 for control of cryogenics during the first superconducting RF cavity tests at CEBAF. In August, 1988 the control system was installed at the Cryogenic Test Facility (CTF) at CEBAF. CTF generated liquid helium in September, 1988 and is now in full operation for the current round of cavity tests. TACL is providing a powerful and flexible controls environment for the operation of CTF.

THE CRYOGENIC SYSTEM AT CEBAF

Overview

CEBAF's cryogenic system will consist of three stations - the Central Helium Liquifier (CHL), the Experimental End Station Refrigerator (ESR), and the Cryogenic Test Facility (CTF). CTF has been in operation since the fall of 1988 and will contiunue to service the test laboratory after CEBAF construction is complete. Construction is now underway for CHL with completion planned for July, 1990. ESR is an existing machine which is being moved from Lawrence Berkeley Laboratory and will be overhauled and commissioned in 1992.

CHL will provide the refrigeration and liquid production for the superconducting RF cavities used in the linacs at CEBAF. It will produce 12 kW of shield refrigeration at 45 K, 4.8 kW of refrigeration at 2.0 K, and liquid helium production of 10 g/sec. at 4.5 K. Upon completion, CHL is expected to be, by a factor of 10, the world's largest 2 Kelvin refrigerator.

CEBAF will contain three experiment halls which will each be fed by a separate transfer line. ESR will be used for cooling a large toroid magnet, as well as several large quadrupoles and dipoles. The refrigerator will produce 1.5 kW of cooling, along with 3 g/sec. of liquid. A transfer line from CHL will be available for additional liquid helium needs.

CTF has been designed to provide helium refrigeration and liquefaction from 4.5 K to 2.0 K for use in the CEBAF test laboratory. CTF users include production testing of superconducting cavities, cryomodules and magnets, injector R & D, and accelerator R & D. The facility consists of three compound helical screw compressors, three cold boxes, a warm vacuum pumping system, a helium purifier, an oil processor, and auxiliary distribution equipment. The first cold box provides 1kW of shield cooling for the cryomodule shields and for transfer lines. The second has three operating modes - a 4.5 K liquifier at 5 g/sec., a 2.0 K liquifier at 8 g/sec., and a 4.5 K refrigerator at 550 watts. The third cold box provides liquid at 2 g/sec. to a 1000 liter dewar. With these capabilities it is possible for CTF to supply a number of different users simultaneously.

Special Control Problems in Cryogenics

The fundamental control problem in refrigeration is the precise maintenance of pressures and temperatures throughout the system. In CTF these are influenced by variable-position valves and variable-speed motors on expanders. It is therefore necessary to maintain very precise control of these valve positions and motor speeds. This is done in CTF through the use of software proportional, integral, and differential (PID) feedback loops and two custom-built CAMAC modules.

Another critical issue is the necessity for 24 hour a day, non-stop operation of the refrigerators. A controlled shutdown and startup of any of the refrigerators can take a minimum of several days. An uncontrolled shutdown can result in the loss of thousands of dollars of helium as pressures are relieved in the system by release of helium through safety valves. Extensive fault protection is built into the TACL system to minimize interruptions in operation.

TACL CONTROL SYSTEM

Overview

TACL is being developed at CEBAF to control machine operations. It provides a fully adaptable system for CAMAC interface, for sophisticated logic manipulations, and for easy generation of custom screens for operator control. The software runs under UNIX on Hewlett-Packard series 9000 workstations and was developed in the C programming language. CEBAF will use a distributed network of 7 supervisory and 50 local computers when commissioned in 1993.

Early in CEBAF's design, it was determined that then-existing control systems would not be adequate for CEBAF's needs. Two critical decisions were made at that early stage which were somewhat unusual for such a long-term project. The first was to use as much as possible the state of the art in computer hardware, operating systems, and languages to produce a set of tools in order for users of the software to build the control logic and screen displays necessary for their particular application. These users would include engineers and physicists working on specific aspects of the CEBAF design, as well as the staff of the controls group. In CTF the entire definition of the logic database and the building of the screen displays has been done by one electrical engineer with the assistance of a part-time high school student.

The second decision was to develop the software very early in the project so that it could be used in all of the pre-construction tests, thereby providing familiarity for the users of the system, as well as giving the users time to critique the system and offer suggested improvements well in advance of the commissioning of the full accelerator. Version 1 of TACL was developed in approximately 2.5 man-years and was available in November, 1987 for control of the first RF cavity tests. Version 2 required about one additional man-year and was first used in the spring of 1988, and in addition to being used throughout the CEBAF test facilities, is also being used to control an operational Tandem accelerator at LLNL.

Though Version 2 contained 80-90% of the capabilities needed for operation of the accelerator, it was decided that Version 3 should incorporate a much improved user interface, speed improvements, and a host of features to facilitate control of the accelerator. A set of standard menus and dialog boxes was developed and incorporated into each of the TACL programs. Full zoom and pan capabilities were added. The networking memory interface was redone which resulted in significant increases in speed. Many additional logic functions and display elements were created. This has required an additional 4-5 man-years of development. Though some minor enhancements will likely be made to Version 3, it is believed that this version is capable of handling the CEBAF commissioning and operation.

Logic Editor

The TACL Logic Editor is an icon-based database editor. One section of the editor is used to define all of the hardware interfaces in the system. These include LAN connections between computers and the definition of all CAMAC crates and modules. A name is assigned to each CAMAC I/O point in this section.

The second section of the Logic Editor is used to define the logic flow of the system. The user places icons, which represent logic functions, on a 100 x 100 grid (expandable to 100 x 1000). As this logic diagram is being drawn, a database is being generated which will be executed at run-time. Logic functions are available for I/O operations, math functions, boolean algebra, as well as a number of custom control algorithms such as the PID loop. Users may also define their own logic functions.

Display Editor

TACL's Display Editor provides extensive drawing capabilities, and can be used to link symbols to the system logic in order to display different states of system variables at run-time. Drawing functions include lines, labels, numeric display boxes, user-defined symbols, bar graphs, dials, and two custom PID displays. Symbols can be built which when selected with a mouse button at run time will toggle a variable in the logic database. Other symbols can be built to change color, size, text, etc. when a value changes in the database.

The cryogenics staff have built 20 process flow screens for the operation of CTF. One of these is a compressor page which represents the piping from storage to the compressors and supply to the cold boxes. The compressors can be reset and started from this screen using the mouse. Other pages represent each of the cold boxes, the transfer lines, and the helium storage. In addition several screens of PID displays are used for tuning PID parameters.

Run-Time

At the start of a run, four processes are executed. All of the processes use shared memory for access to the database and for inter-process communication. The Network process uses HP Link Level Access for transfer of the database between computers. The Logic process evaluates the logic array, updates the database in shared memory, and handles CAMAC I/O. The Disc process logs data to disc once every minute. The Run-Time Display process provides the user interface to the system using the displays built through the Display Editor. In addition to these processes, users may write their own processes which can be accessed through the Run-Time Display, and can directly communicate with the database in shared memory.

Graphs

The TACL Graphs program can plot value versus time graphs for up to 10 parameters at a time in 10 colors. The Graphs program has two modes of operation. The first is a real-time mode in which the program accesses data from shared memory and displays a running strip-chart of data for the 10 parameters. The amount of data on screen can vary from 15 minutes to 2 hours. In the second mode, the Graphs program can be used to call back data from disc that has been logged by the Disc process. In this mode any time range can be requested by the user. It is possible to zoom in on sections of the graphs.

The cryogenics group keeps a real-time Graphs screen active at all times to monitor trends of critical pressures, flows, and temperatures. Data retrieval from disc is especially useful during the cavity tests to determine heat loss in the cavities, and is also used for examining failures and stabilizing long time constant PID's.

PID Algorithm

The software PID feedback loop was developed at CEBAF for control of valves and motor speeds in order to maintain pressure and temperature settings. The implementation provides for run-time setting of the following parameters: input set value, sample time, gain settings, maximum and minimum position, maximum and minimum change, and loop enable and disable.

In addition to numeric display of the current input and output of the loop, bar graphs and a running 5-minute time graph of the input, output, and set value are provided for each PID in the system. With this full PID display, 3-4 PID's can be shown on one screen. A small PID display is also provided which shows a subset of the full PID data and can be used as part of a more complex flow diagram.

The algorithm used was based on reference [3]. The Logic Analysis program checks for each PID if more than the defined sample time has elapsed. If the time has not elapsed, the output of the PID does not change. If the time has elapsed, a new output is computed from the following formula:

$$\begin{aligned}\text{Output Change} = {} & (PG + IG*ST + DG/ST) * ER(n) - \\ & (PG + 2*DG/ST) * ER(n-1) + \\ & (DG/ST) * ER(n-2)\end{aligned} \qquad (1)$$

where,

PG = Proportional Gain
IG = Integral Gain
DG = Differential Gain
ST = Sample Time
ER = Error (Set Value - Actual Value)
n = Current Sample Number

The program saves the Error values from the last two output calculations, and uses them in the computation of the new output. Once the output is computed, the program checks that this output will not exceed the currently set maximum or minimum limits, either in absolute position or in change from the last output value. Setting of the gains by operators currently involves some trial and error and experience with setting previous loops. Once the gains are properly set, it is generally not necessary to change these unless changes are made to the hardware. Some type of gross self-tuning algorithm is being investigated to aid in configuring new PID's.

Two types of PID output can be selected by the user. In one, the output is the amount of change from the current position. This is used in CTF to control electric and hydraulic valves through the custom CEBAF electric valve driver card. In this case the counts sent to the CAMAC card represent a pulse length in msec to drive the valve. In the second type of output, an actual position is sent to a CAMAC module, which in CTF's case is a 0-24mA current module. For this type of output, protections are built into the PID algorithm to assure that on program startup the actual position of the valve or motor is sent to the card until the algorithm has run a complete cycle. CTF currently uses 36 change type PID's for controlling valves and 4 position type PID's for controlling expander engine speeds and vacuum pump motor speeds.

A new feature was recently added to the program to allow the output of one PID to be the set value for a second PID. Using this technique, it is possible to cascade any number of PID's. In CTF, this technique is used to control the mass make-up valve on the input of the compressors using both the suction and discharge pressures. This helps to minimize losses of helium in the event of a compressor shutdown.

Fault Protection

Several levels of fault protection have been built into TACL. In the event of a power failure on the computer, when the power is restored, the computer will reboot and then will start a run, returning the system to the settings that were in effect at the time of the failure. This allows CTF to run unattended and not be adversely affected when brief interruptions of power occur. Uninterruptable power supplies will be added in the future which will increase the time that the system can be without power.

In order to maintain high-speed I/O to the CAMAC crates, the run-time Logic program addresses only the controller module using the F0 scan CAMAC command to do a block read of an entire crate in about 2 msec. The program then parses the data into the database. The disadvantage of this technique is that if a module fails or is removed, the data received does not match the database. The solution to this problem was to use a module in the last slot in the crate that contains a two-byte register. The current read count is stored in this register. If this count is not the last byte read from the crate, the program addresses each card individually to determine which card has failed. The new read count is then loaded into the register and the scan reads continue. Information on which slot has failed is then passed to the operator. This has made it possible to remove and replace cards while running, without affecting the status of any other cards in the crate.

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